Critical flow rate and speed of sound, converted isentropic flow rate and Mach number for gas injector design

The design of gas injectors involves many physical parameters and related calculations. One of these parameters is the critical flow rate.

On some occasions, we often see supercritical or subcritical jets and often think that this concept should be related to supersonic subsonic speeds. Let's take a look at what these two are really about.

It is actually relatively easy to see the difference in the definitions of the two.

The speed of sound is defined as the speed of propagation of sound in a given medium and is expressed by the following equation.

$$\alpha = \sqrt{k * R * T}$$

That is, the speed of sound is related to a given medium and its temperature, specifically to the molar mass, adiabatic index and temperature of the medium. For a medium that can be considered an ideal gas, the adiabatic index is only a function of temperature, and thus the speed of sound depends only on the molar mass and the temperature.

The critical flow rate is defined as the velocity of flow of a medium that reaches the speed of sound in the medium in the corresponding state. Critical flow rates of gases are usually found in nozzle configurations, where parameters such as pressure or temperature are usually expressed in terms of stagnation parameters. For simplicity , the hysteresis parameter is usually the parameter of the nozzle inlet, and the parameter is marked with a subscript “0”. The critical flow rate expressed in terms of the hysteresis parameter is defined as

$$\alpha * = \sqrt{2 * \frac{k}{k+1} * R * T_0}$$

When the critical flow velocity is equal to the local speed of sound, then there are:

$$\frac{T}{T_0} = \frac{2}{k+1}$$

This is the expression for the relative temperature when the discounted isentropic velocity of the gas reaches the critical flow rate.

The ratio of the isentropic velocity of a gas to the local speed of sound is the Mach number, usually denoted by M, while the ratio of the isentropic velocity of a gas to the critical flow velocity is the discounted isentropic velocity, usually denoted by λ. The ratio of the isentropic velocity of a gas to the local speed of sound is the Mach number. When the stagnation temperature of the gas is equal to the ambient temperature, it is obvious that the critical flow velocity is less than the local speed of sound of the medium

The relationship between Mach number and converted isentropic velocity is as follows:

$$M = \lambda * \sqrt{\frac{1}{\left(\frac{k+1}{2} - \frac{k-1}{2} * \lambda^2\right)}}$$

Based on the above relation equation, the following conclusion can be obtained:

1. When the isentropic flow rate of the gas is zero, the Mach number is also zero, i.e., the gas is at rest.

2. When the isentropic flow rate of the gas is 1, the Mach number is also 1, i.e., the flow rate at the nozzle outlet when the critical jet occurs is exactly equal to the speed of sound in the stagnant state. The isentropic velocity of the gas in the nozzle is less than 1, that is, the occurrence of subcritical injection, greater than 1 is supercritical injection;
3. The larger the isentropic flow velocity, the larger the corresponding

Mach number. Note that the maximum value of the Mach number is infinity, while the maximum value of the isentropic flow rate is

$$\lambda max = \sqrt{\frac{k+1}{k-1}}$$

The maximum converted isentropic velocity of air at room temperature is 2.45, while its corresponding Mach number is infinity.

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email:lzx@cd-greenwater.com